TRAFFIC IMPACT STUDY

WOLF TRAP NATIONAL PARK FOR THE PERFORMING ARTS
FAIRFAX COUNTY, VIRGINIA

SUMMER 2003

This study was prepared by Ponlathep Lertworawanich under the grant from Ford Motor Company in partnership with the National Park Foundation and the ENO Transportation Foundation.

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CHAPTER 1 INTRODUCTION

The mission of the National Park Service is to preserve the national parks and to provide for the enjoyment for those parks in a way that will leave them unimpaired for future generations. As visitation to the parks grows tremendously every year, the challenge of ensuring resource protection while accommodating visitors and providing enjoyable experiences for them requires planning and sustainable, environmentally-friendly roads and transportation systems. Ford Motor Company in partnership with the National Park Foundation, the National Park Service, and the ENO Transportation Foundation generously sponsors a grant for Ponlathep Lertworawanich, the author of this report, to conduct a traffic impact study at Wolf Trap National Park for The Performing Arts located in Vienna, Virginia.

Wolf Trap National Park provides the Washington, D.C. metropolitan area with outdoor venue for performances of every genre. A typical performance season starts from late May to early September of every year. Over the past ten years, the park has continued to refine parking and traffic procedures but visitors complaints on parking and traffic circulation continued to be the first-priority complaint received by the park management. A heavy mix of pedestrian and vehicular traffic is observed before and after the performance. Therefore, it is intended that this study will serve as a starting point for a future transportation planning effort at the park. The traffic impact study was conducted between June 3, 2003 and August 29, 2003.

The objectives of the study are:

- To collect traffic and parking data as well as both temporal and spatial visitor demands during the 2003 season,
- To document and evaluate the adequacy of the existing parking operations and traffic circulation within the park and the neighboring areas,
- To provide recommendations to enhance the parking operations and the traffic circulation conditions in the park,

- To evaluate and provide recommendations for signing, lighting, and walkways to promote pedestrian safety in the park,

In the remainder of this report, the summary of the existing visitor demands, parking operations, traffic circulation is provided in chapter 2. Chapter 3 describes the existing vehicular traffic operations. The recommendations to ameliorate both ingress and egress traffic circulations are also provided in chapter 3. Signing, lighting, and walkways to promote visitor safety along with the relevant recommendations are discussed in chapter 4. Chapter 5 presents the findings, the final conclusions, and the recommended future study.

CHAPTER 2 EXISTING CONDITIONS

This chapter provides a summary of existing conditions of the Wolf Trap National Park for The Performing Arts. It consists of five sections. The first section presents a concise description of park activities. The study area of this traffic impact analysis is defined. Typical traffic demand and visitation are outlined in the second section. The third section discusses the existing incoming traffic circulation and parking management followed by the egress traffic circulation. The last section provides traffic-related problems of the existing conditions.

2.1 Park Activities and Study Area

The Wolf Trap National Park for The Performing Arts is located in Vienna, Virginia. It provides the Washington, D.C. metropolitan area with outdoor venue for performances of every genre. The Filene Center, operated in partnership with The Wolf Trap Foundation, houses approximately 95 evening shows annually from late May to early September. Activities for Children are also provided at Children's Theatre-in-the-Woods at Wolf Trap National Park. These performances usually generate smaller number of attendance than evening shows. Figure 2.1 presents historical visitations at Wolf Trap National Park. These numbers represent all visitations to the park.

Figure 2.1: Historical Visitations at Wolf Trap National Park

Generally, in each season between 25 and 30 evening shows are sold out. Note that The Filene Center can hold roughly 7000 visitors including both in-house and lawn seats.
In 2003 season, there are 95 evening performances from May 21st through September 14th. Eleven shows are sold out (based on the information from May 21st through August 25th 2003). The average performance in 2003 has an attendance equal to 4550 or 65 percent of capacity.

In this study, the study area is defined so that effects of park activities on traffic circulation can effectively be evaluated. Figure 2.2 shows a map of the study area. Note that The Barnes of Wolf Trap is also a part of the study area even though it is NOT operated by National Park Service.

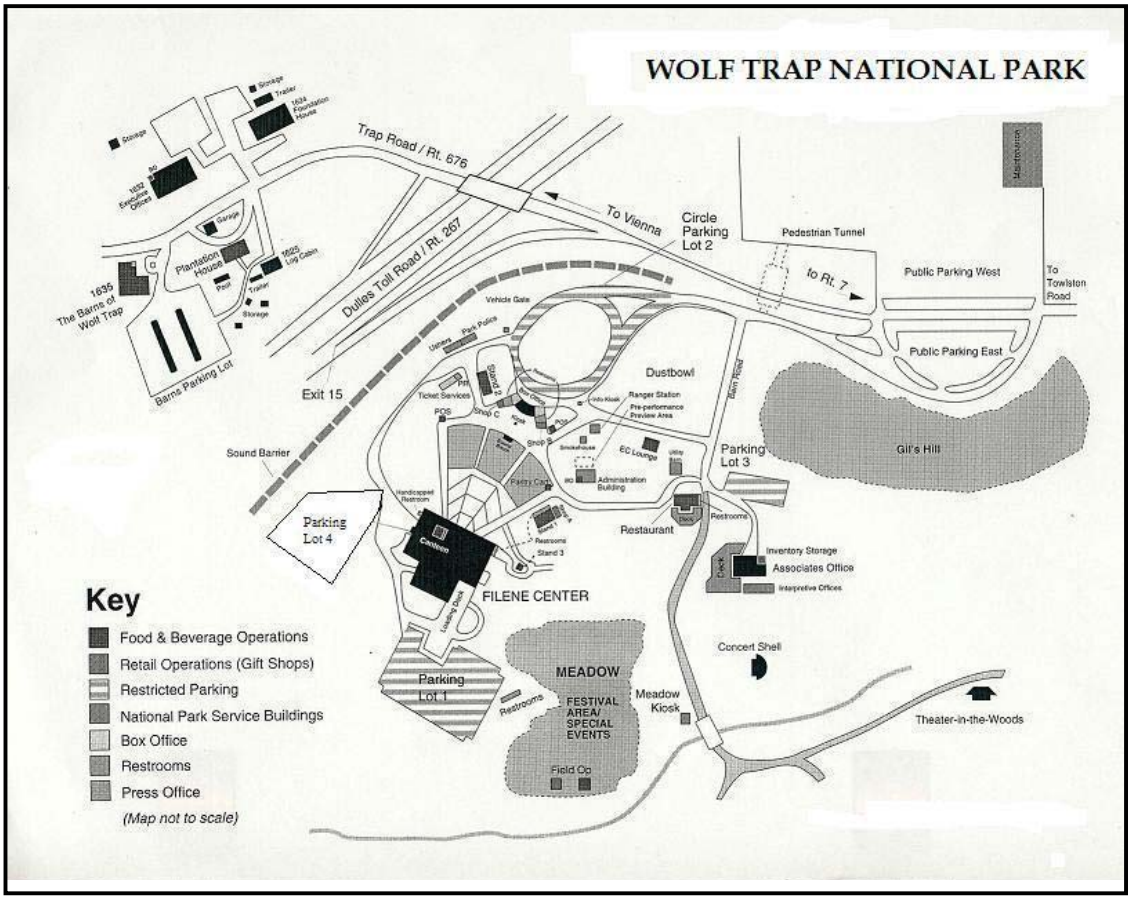


FIGURE 2.2: Map of the Study Area

There are two major routes to Wolf Trap National Park. The north access is through Route 7-Leesburg Pike while the south access is through Toll Rd (VA-267).

2.2 Visitor Demand Patterns

Visitor demand patterns are an integral part of this traffic impact study as it provides crucial information on both when and how visitors arrive at the national park. According to the 1993 traffic impact report by Robert Peccia & Associates, it was found that 70 percent of traffic arrives the national park from the south via VA-267 Toll Rd. while the rest comes from the north via Route 7-Leesburg Pike. The average occupancy rate was 2.2 persons per vehicle for a typical performance. In order to update these findings with the existing condition, data collections are necessary.

Data collections on traffic demand were conducted on June 21st, July 1st, and July 12th of 2003 to determine visitor and traffic demand patterns. Norah Jones and Sheryl Crow opened their concerts on Saturday June 21st and Tuesday July 1st with the number of tickets sold of 7040 and 7071 respectively. Both concerts were considered sold out. However, during the Norah Jones's concert some on-site parking lots were not filled to their capacity due to an unusual long period of rains till the middle of June. There was a threat of rain just prior to the show. Contrary to June 21st, the weather was clear during the Sheryl Crow's concert. National Symphony Orchestra (NSO) with Marvin Hamlisch as a conductor opened their show on Saturday July 12th with the number of tickets sold of 5780. It was not a sold-out show. Note that this NSO drew higher number of senior patrons than the first two performances, which attracted more young patrons.

Vehicle counts were done at three entrances: 1) the upper intersection (close to VA-267 interchange), 2) the lower intersection, and 3) the entrance to the West Lot from 5 pm to 8 pm to determine a temporal distribution of demand. Please see Figure 2.3 for further details of each location. In this study, different types of visitors are classified according to different types of permits each visitor holds. There are four categories of visitors, namely 1) normal visitors, 2) handicapped visitors, 3) permit visitors, and 4) VIP visitors. Normal visitors do not hold any parking permits. Handicapped visitors hold valid handicapped tags or purple permits, which are issued by park rangers. Permitted visitors hold gold permits or white permits issued by the Wolf Trap Foundation or the park. All other permit-holders are considered VIP visitors (the donors to the Wolf Trap Foundation). Normal visitors are not allowed to access the Wolf Trap national park via the upper intersection. Based on the observations, percentage of visitor type is summarized and shown in Table 2.1.

TABLE 2.1: Percentage of Visitor Type Based on Three Days of Observations

Show	Type of Visitor (%)			
	Normal	Handicapped	Permitted	VIP
Norah Jones	89.2	2.2	1.1	7.5
Sheryl Crow	90	1.5	1.8	6.7
Marvin Hamlisch (NSO)	83.4	8.2	1.9	6.5

From Table 2.1, it is indicated that nearly 90 percent of visitors do not hold any permit and about 10 percent of visitors possess parking permits. However, the number of handicapped visitors increases dramatically for the national symphony concert. Note that the actual number for each type of visitors can be determined from this percentage, and the number of tickets sold.

Temporal distributions of arriving visitors are evaluated based on the observations at the three main entrances. It is found that less than four percent of visitors arrives the park before 5 pm. The majority of visitors arrive within 2 hours before the show time. However, there are some visitors arriving after the performances begin. Table 2.2 represents temporal distributions of arriving visitors as observed during the course of data collection.

TABLE 2.2: Temporal Distributions of Arriving Visitors

Show	Percentage of Arriving Visitors			
	Before 5 pm	5 – 6 pm	6 – 7 pm	7 – 8 pm
Norah Jones	2.3	16.3	40.2	41.2
Sheryl Crow	3.5	11.0	43.7	41.8
Marvin Hamlisch (NSO)	1.0	9.3	36.8	52.9

However, the temporal distributions of different types of visitors can be different from one another. The values provided in Table 2.2 are based on the entire population of visitors. As expected, during the national symphony concert, more half of the visitors arrive within one hour before the show time.

An occupancy rate is one of the good indicators for predicting the number of parking spaces required in the national park. With the same number of visitors, as the average occupancy rate goes up, number of required parking spaces decreases. Therefore, an accurate estimate of vehicle occupancy is an essential piece of information for park rangers to operate parking facilities. Again, the average occupancy rate is estimated using data obtained from the three days of observations and presented in Table 2.3.

TABLE 2.3: Average Occupancy Rate

Show	Average Occupancy
Norah Jones - Sat	2.40
Sheryl Crow - Tue	2.39
Marvin Hamlisch (NSO) – Sat	2.41

Unlike the study conducted in 1993 where average occupancy was estimated from visitors of small sample size less than 2000 vehicles, this study considers every vehicle that was present in the national park. It provides more accurate results. The findings show that the average occupancy rate is about 2.40 visitors per vehicles for a typical show. There is only a slightly difference in occupancy rates between weekday and weekend.

Number of walk-up visitors who show up and buy tickets on the day of performance is estimated based on the information obtained from the ranger's logbook for two different weather conditions, rain or no rain. Table 2.4 presents number of walk-up patrons based on the number of ticket pre-counts and weather conditions.

TABLE 2.4: Number of Walk-up Patrons

PRE-COUNT	NUMBER OF WALK-UP VISITORS (persons)	
	RAIN	NO RAIN
1000	**200**	**200**
1500	**150**	**200**
2000	**150**	**250**
2500	**200**	**250**
3000	**100**	**300**
3500	**100**	**500**
4000	**100**	**300**
4500	**200**	**250**
5000	**250**	**300**
5500	**250**	**300**
6000	**200**	**300**
6500	**200**	**300**
7000	**NA**	**NA**

This table can be used to estimate number of walk-up patrons. However, cautions should be taken when the rain category is considered since the estimates are based on limited number of observations.

2.3 Incoming Traffic Circulation and Parking Management

As discussed earlier, there are four types of visitors based on different types of permits. Permit holders and handicapped visitors are allowed to enter the national park using the upper intersection. Visitors without permits are only allowed to use the lower intersection. The upper gate of West Lot is closed at all times as shown in Figure 2.3.

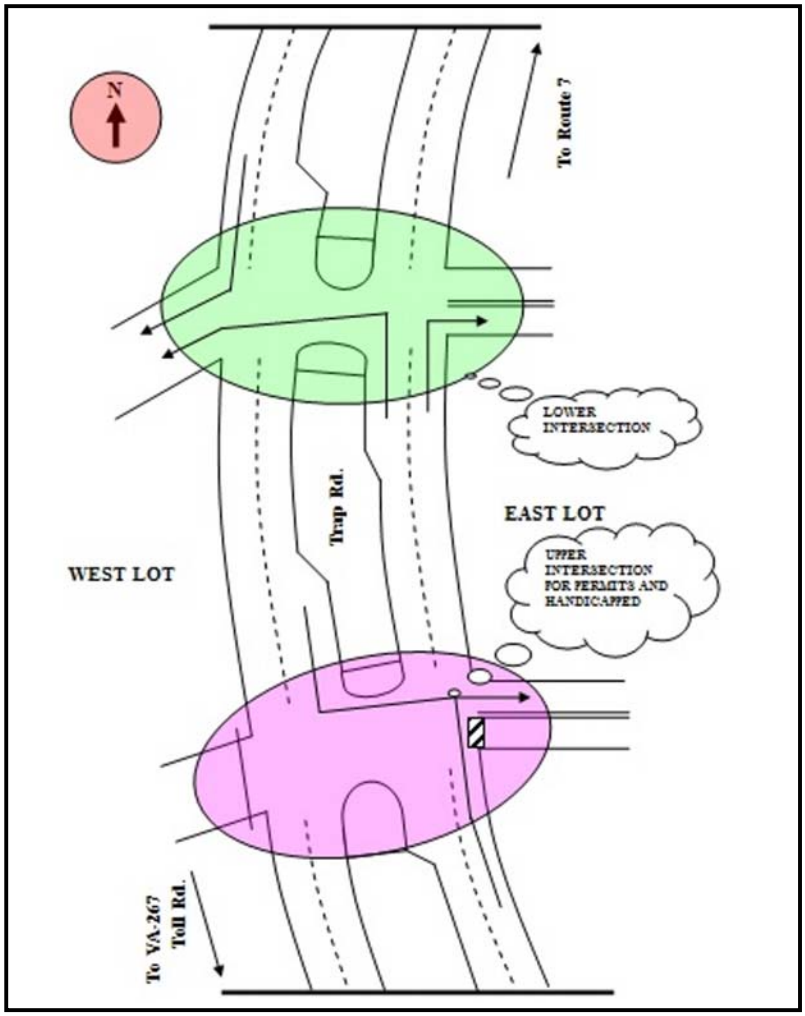


FIGURE 2.3: Lower and Upper Intersections

Field observations indicate that about 70 percent of the concert visitors arrive via Trap Rd from the south entrance to the Park. Most of these people are using the Dulles Toll Rd. (VA-267). The other 30 percent of the vehicles arrive through the north entrance on Trap Rd. The observations affirm the findings of the 1993 traffic impact report. It is also found that some vehicles stop at the upper intersection to ask police officers for direction and parking information. This incurs delays and traffic congestion on Trap Rd.

Wolf Trap National Park has a total of 1635 designated paved parking spaces and 1296 turf parking spaces. The inventory of parking spaces was conducted to identify capacity of each parking lot as summarized in Table 2.5 with the location shown in Figure 2.4.

TABLE 2.5: Parking Space Inventory

Parking Area	Surfacing	Capacity (spaces)	Type of visitors Allowed to park
1. Lot 1	Paved	150	Red permit (VIP)
2. Lot 2 – Circle except triangle	Paved	90	Green permit (VIP)
3. Triangle	Turf	50	Green permit (VIP)
4. Lot 3	Paved	70	Gold or white permit (Permit)
5. Lot 4	Paved	75	Purple permit (Handicapped)
6. Dust Bowl	Turf	200	Anyone (Normal)
7. Gil's Hill	Turf	900	Anyone (Normal)
8. Grass Area near Pedestrian Tunnel	Turf	40	Anyone (Normal)
9. Grass Area near Marquee	Turf	26	Anyone (Normal)
10. East Lot	Paved/Turf	350/80	Anyone (Normal)
11. West Lot	Paved	900	Anyone (Normal)
TOTAL SPACES		2931	

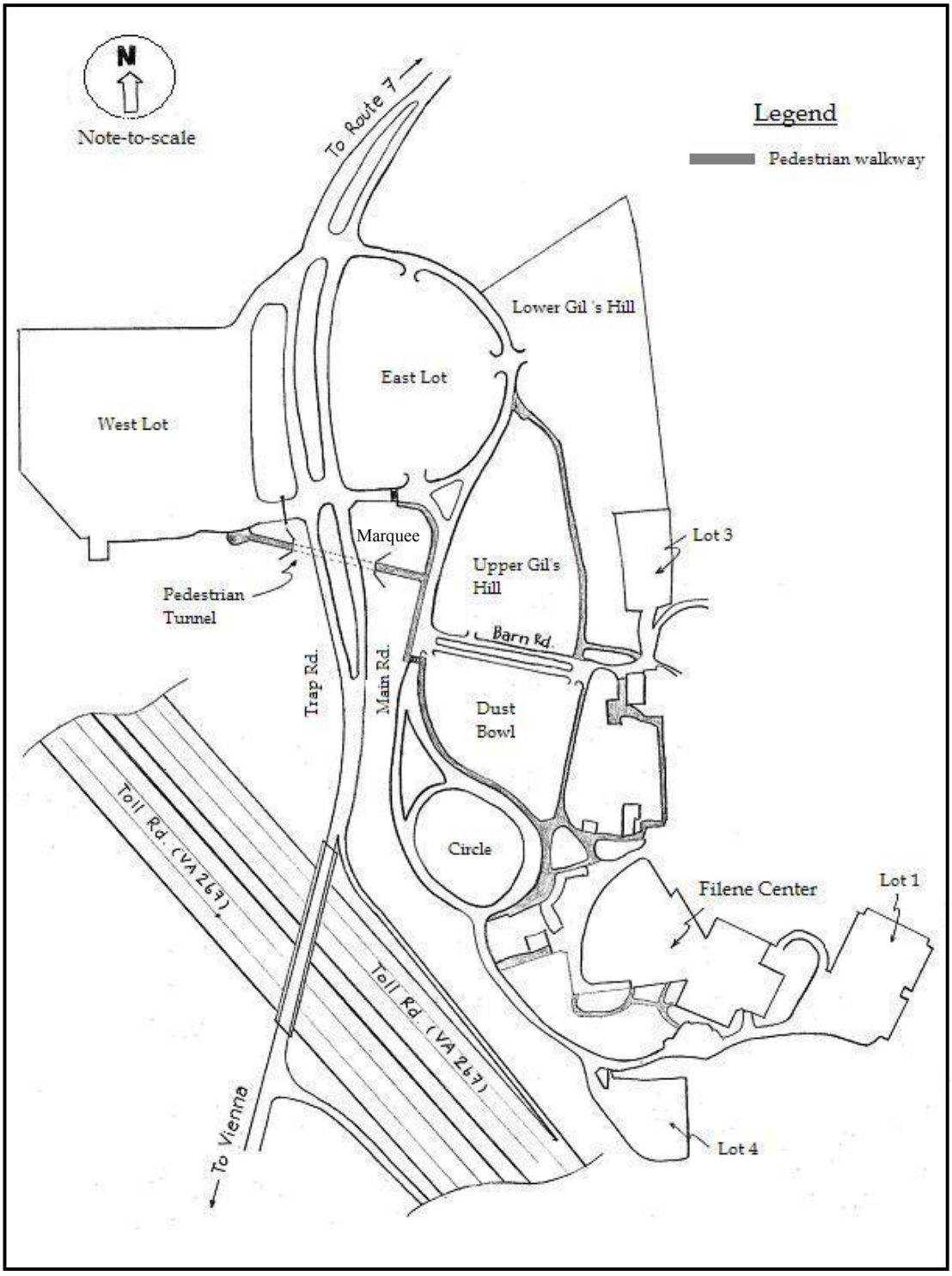


FIGURE 2.4: Map of Parking Area

According to the surveys and the interviews with park personnel, for a typical night park and wolf trap foundation employees occupy an average of 195 paved parking spaces. Therefore, there are approximately 2736 spaces available for visitors. However, these numbers vary from day to day due to a security restriction imposed for different performances, number of visitors, and weather conditions. Note that there were a lot of rains in early June 2003. This resulted in reduction of usable spaces on the turf parking areas.

Parking management in the park is operated by two different crews, namely 1) park rangers and 2) parking crews. Park rangers direct all permit-parking except Lot 3 while parking crews run the rest of parking facilities. Self-parking is allowed until two hours before show time. Then, the parking crews take control of parking. Typically, the parking crews park the small turf areas near the pedestrian tunnel and the marquee first as it takes more time to load. Next, Dust Bowl and Gil's Hill are loaded. According to the field observations, the existing parking operations can be summarized as follows.

Existing Parking Operations

1. West Lot remains open for patrons to enter and park where they choose.
2. The Dust Bowl is parked by the Parking crew until it is full. The middle entrance to the East lot is controlled to allow patrons to enter and park where they choose, (a relief valve while grass parking is in operation).
3. The top of the Gil's Hill is parked by the crew; upon filling of the East lot, the median around the lot is parked by part of the crew.
4. Upon filling of the West lot, the lot gates are closed and maintained by the U.S. Park Police; all cars are directed into the lower East entrance in two lanes.
5. When the East lot median is full, the lower portion of Gil's Hill is parked by the crew. Upon the completion of parking on the top of the Gil's Hill, the Hilltop lawn will be parked by the crew.
6. Cars are parked on the triangle by the park rangers; available spaces in Lot 2 are filled.
7. Cars are parked on Gil's Hill.

8. Cars are parked on the grass adjacent to the east entrance of the pedestrian tunnel. Simultaneously, cars are parked around the marquee, on park property.
9. Upon the completion of step 8, the Park entrances will be closed to all traffic except cars with parking permits and handicapped/disabled patrons. The decision to close the park to vehicular traffic will be made by the park rangers, in consultation with the parking crew supervisors and U.S. Park Police. Closure actions will be the responsibility of the U.S. Park Police.
10. U.S. Park Police park the shoulders of Trap Rd until filled up then advise any additional patrons to go north on Trap Rd to find legal parking in the adjacent neighborhood. U.S. Park Police do not direct people south toward the Barns of Wolf Trap because the Barns are often in use and because there are no walkways on the bridge over Toll Rd.
11. When possible visitors will be advised the park is closed to vehicular traffic, they may park legally elsewhere and walk in.

With these parking operations, the loading of the on-site parking lots occurs in an orderly fashion. As mentioned in section 2.2, the majority of visitors arrive within 2 hours before show time. Traffic congestion is usually observed about 30 minutes before the show time. A queue of vehicles backs up from the upper intersection onto the on-ramp on Toll Rd and generally dissipates 5 to 10 minutes after the show begins. Parking on the median of Trap Rd is prohibited at all times.

2.4 Egress Traffic Circulation

At the end of a performance, nearly all visitors would like to leave the Filene Center at the same time. Since there are only two exit routes, the exit process of traffic is somewhat in a disorder manner, which results in mass traffic congestion. The first exit route is Route 7(Leesburg Pike) north of the park. The second exit route is via Toll Rd (VA-267) south of the park. Vehicles in Lots 1, 2, and 4 are directed to the upper intersection and are exiting the national park via Toll Rd. Vehicles parked in the Dust Bowl, the Gil's Hill, and Lot 3 are directed to the lower intersection and must exit via Route 7. At the West Lot, visitors have two options. They can depart via either Route 7 or Toll Rd depending on which lane they occupy. The East Lot vehicles are allowed to

exit at either the lower or the upper intersections but they are all directed to VA-267. Note that candle stick delineators are installed along the median of Main Rd to prevent weaving maneuvers across lanes, which can slow down the exiting process. The schematic diagram of the exiting process is illustrated in Figure 2.5.

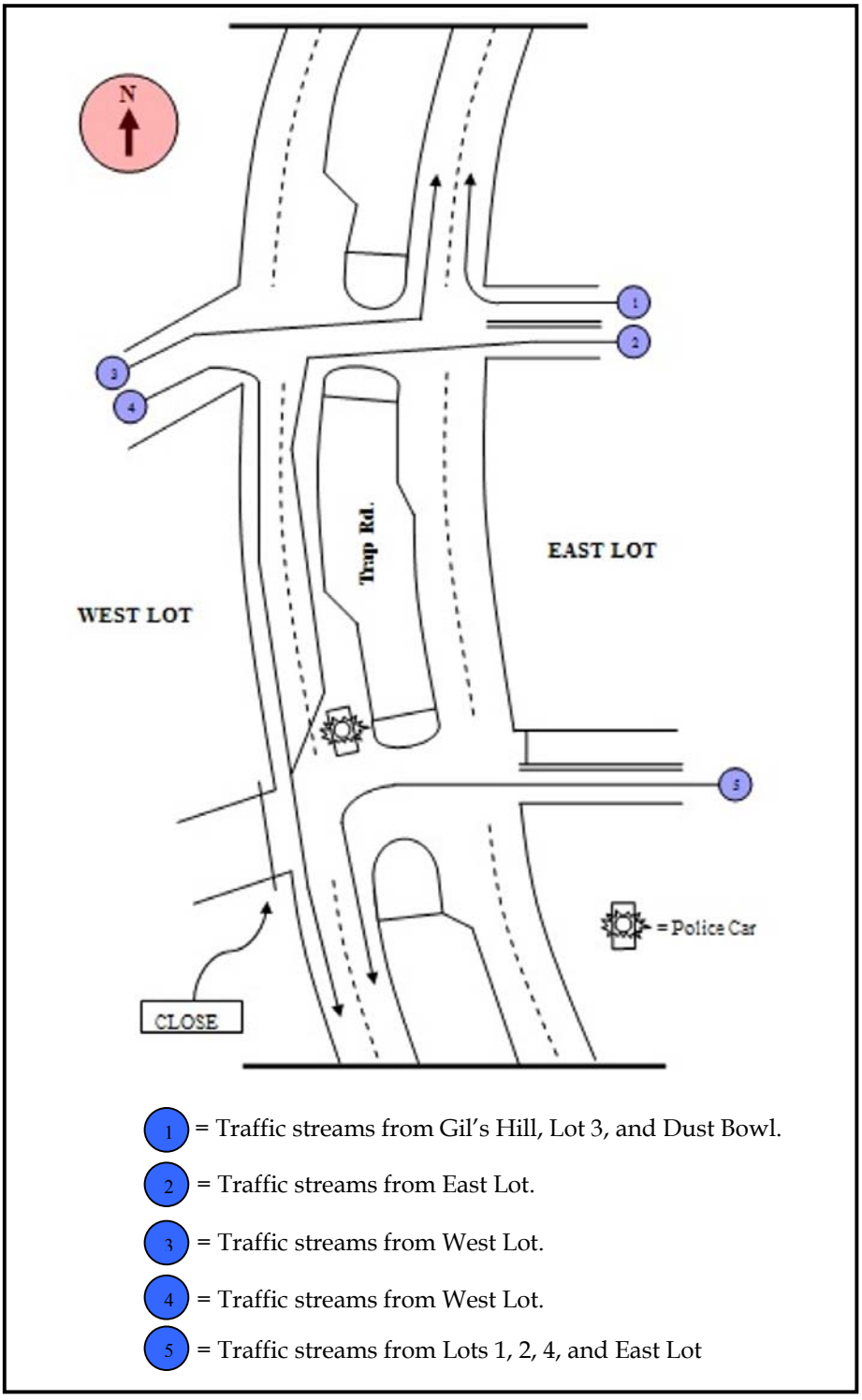


FIGURE 2.5: Current Exiting Traffic Process

Upon exiting the park via Trap Rd to the south, the traffic is merged into one single lane before crossing the bridge over Toll Rd. This becomes a traffic bottleneck. The access ramp to Toll Rd is also one lane. Vehicles must look for gaps of appropriate sizes before merging into Toll Rd. Similarly, traffic exiting via the north also merges into one lane due to vehicles parked along Trap Rd. But they are split into two lanes at the signalized intersection of Towlston Rd. and Leesburg Pike. It is found that this intersection is operating under a pretimed control system with a cycle length of 115 seconds. The phasing diagram of the intersection is depicted in Figure 2.6.

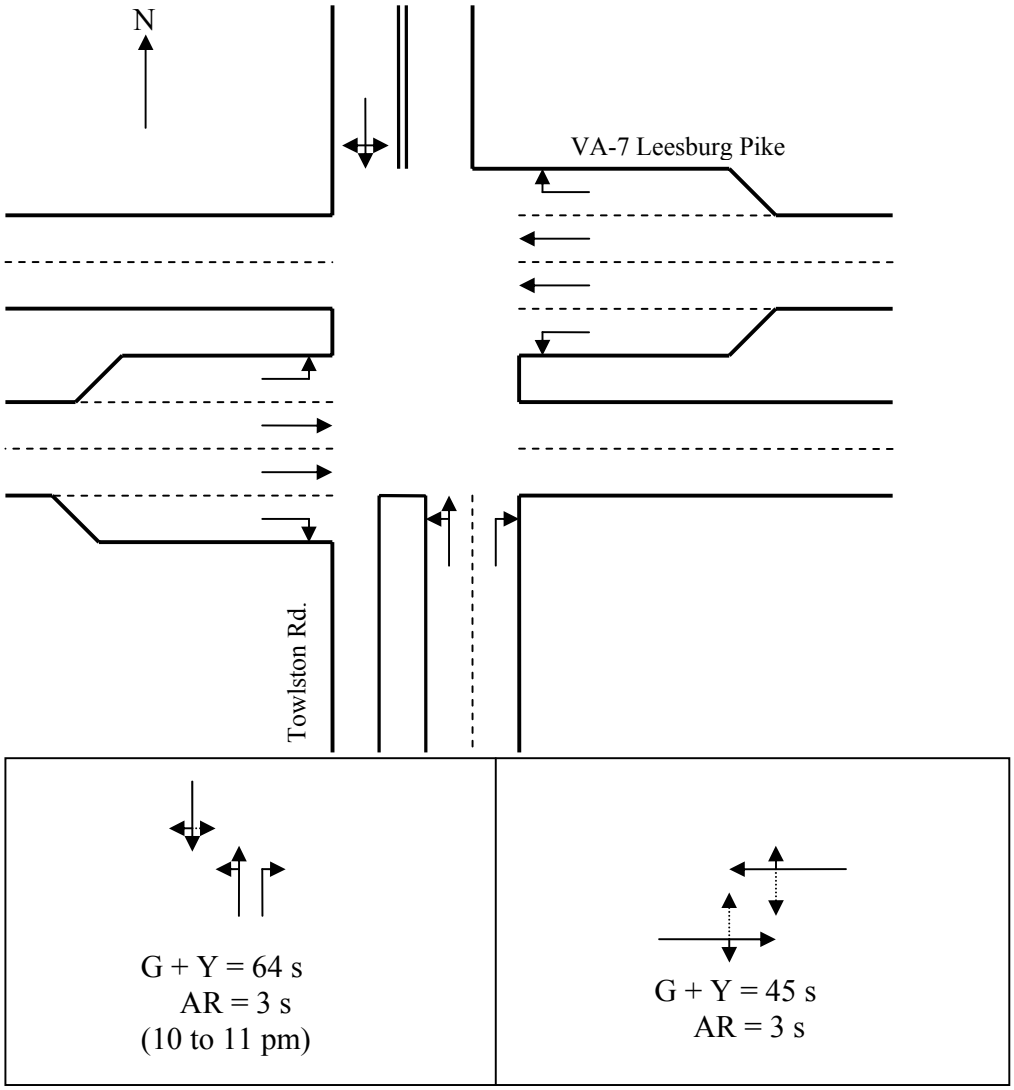


FIGURE 2.6: Schematic Diagram of the Intersection of Leesburg Pike and Towlston Rd. (Observed on June 12, 2003 from 10 pm to 11 pm)

Slower exiting process is regularly observed at the southbound direction than at the northbound direction. On a typical sold-out night, it takes roughly 55 to 60 minutes for traffic to clear. Regression analysis is conducted to fit the relationship between number of patrons and time to clear traffic. Figure 2.7 illustrates this relationship.

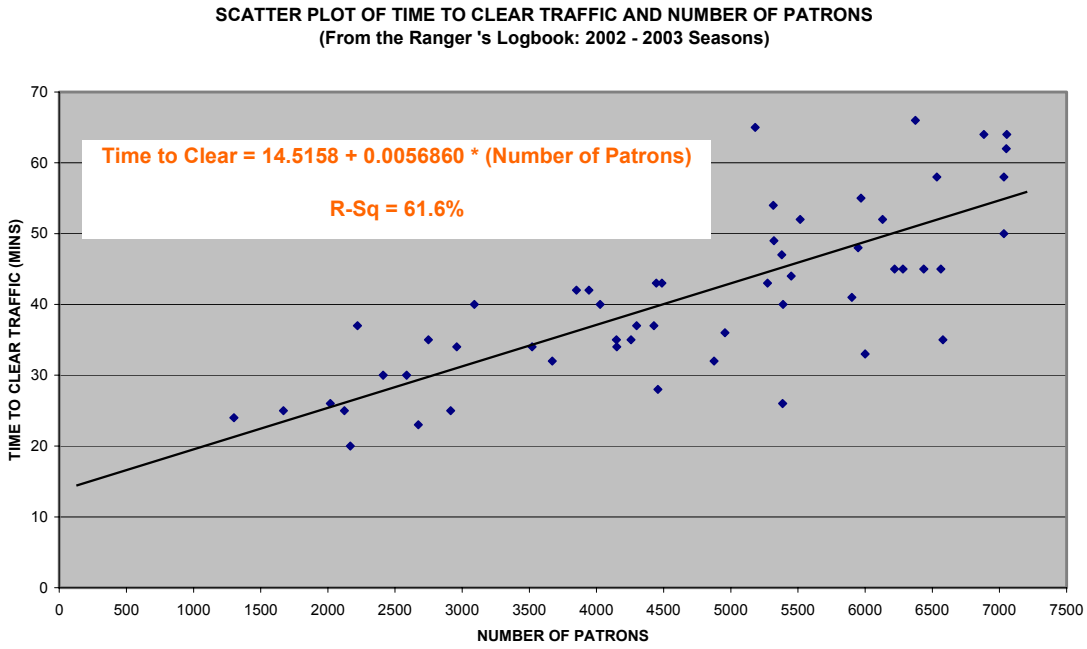


FIGURE 2.7: Relationship between Time to Clear Traffic and Number of Patrons

2.5 Existing Shuttle System

Currently, the Wolf Trap Metro Shuttle operations, partially subsidized by the Wolf Trap Foundation, provide a bus service for visitors between the West Fall Church Metrorail Station and the park. The shuttle bus leaves the West Fall Church Metrorail Station every 20 minutes starting two hours before each performance. Patrons are charged $4.00 per person for a round trip fare. After the performance, the shuttle leaves the park 20 minutes after the show but no later than 11 pm. The data collections indicate that visitors arriving by the shuttle account for less than three percent of total park visitations or less than 100 visitors each performance. It is less likely that this number will significantly increase in the near future given the current marketing operations. The reasons for this are:

- Metro visitors have to pay for metro fares while parking in the park is free.
- Some visitors do picnics at the park. They have picnics coolers and bags with them. Therefore, it is inconvenient to carry these on a metro bus.
- There is no dedicated traffic lane for buses. They share the same roadways and amount of traffic delays during the exit process with other passenger cars. Visitors, therefore, have no incentives to use the shuttle system.

2.6 Pedestrian Traffic

Performances at the Filene Center draw arriving pedestrian traffic from parking areas before the show time. Similarly, exiting pedestrian traffic from the Filene Center to parking areas must be generated accordingly after the performances are over. According to the field observations, pedestrian traffic before the show occurs somewhat in an orderly manner except at the intersection of Barn Rd and Main Rd. This intersection has two painted crosswalks as shown in Figure 2.8. The crosswalk #1 is a functional crosswalk but the crosswalk #2 is not operative before the show time since it leads pedestrians to the wrong direction. However, this crosswalk is functional during the exit process. Therefore, the park has decided to keep this crosswalk. Visitors who park in the West Lot use the pedestrian tunnel under Trap Rd and then walk through this intersection to access to the Filene Center. Visitors who park in the East Lot tend to use two routes to access to the Filene Center. The first route starts from the middle gate of the East Lot and cuts through the Upper Gil's Hill. Pedestrians then walk along a walkway along the upper portion of the Dust Bowl to access to the Filene Center. The second route starts from the East Lot and then walk along the designated walkway through the intersection of Barn Rd and Main Rd. At this intersection, pedestrian traffic is split into two streams. The first stream uses the crosswalk #1 and then follows the designated walkway along the Circle to the Filene Center. The second stream uses the crosswalk #2 and then walks along Bard Rd. to the walkway along the upper portion of the Dust Bowl.

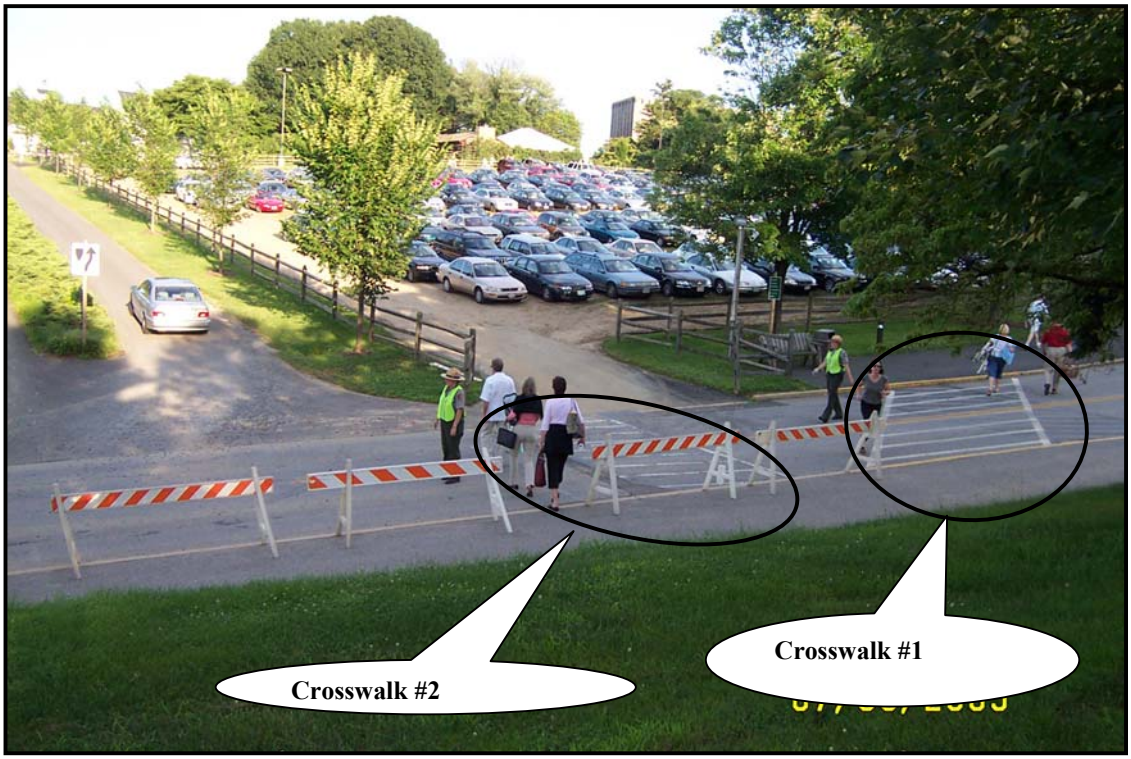


FIGURE 2.8: The Intersection of Barn Rd. and Main Rd.

Pedestrians from the Gil's Hill and Dust Bowl are found to walk in a fairly orderly manner. However, these pedestrians occasionally disrupt vehicle-loading processes as they walk through the vehicle gates on Barn Rd.

The exit process of pedestrian traffic occurs in a disorganized fashion as nearly everyone would like to get to their vehicles at the same time. Visitors leave the Filene Center using three exits: 1) the main exit near the Box Office, 2) the exit near the ranger station, and 3) the small exit behind the park administrative building. The visitors who do not take the main exit are likely to walk down the left lane Barn Rd if they park their cars in the East Lot or the West Lot. These pedestrians then again take the crosswalk #2 shown in Figure 2.7 to cross Main Rd, which creates a major vehicle-pedestrian conflict at the intersection of Barn Rd. and Main Rd. The visitors who take the main exit are likely to take the walkway along the Circle Lot if they park their cars in West Lot or East Lot. Otherwise, they take the walkway along the upper portion of the Dust Bowl to access their cars at

the Gil's Hill and the Dust Bowl. The schematic diagram of the vehicle-pedestrian conflict at the intersection of Barn Rd and Main Rd is shown in Figure 2.9.

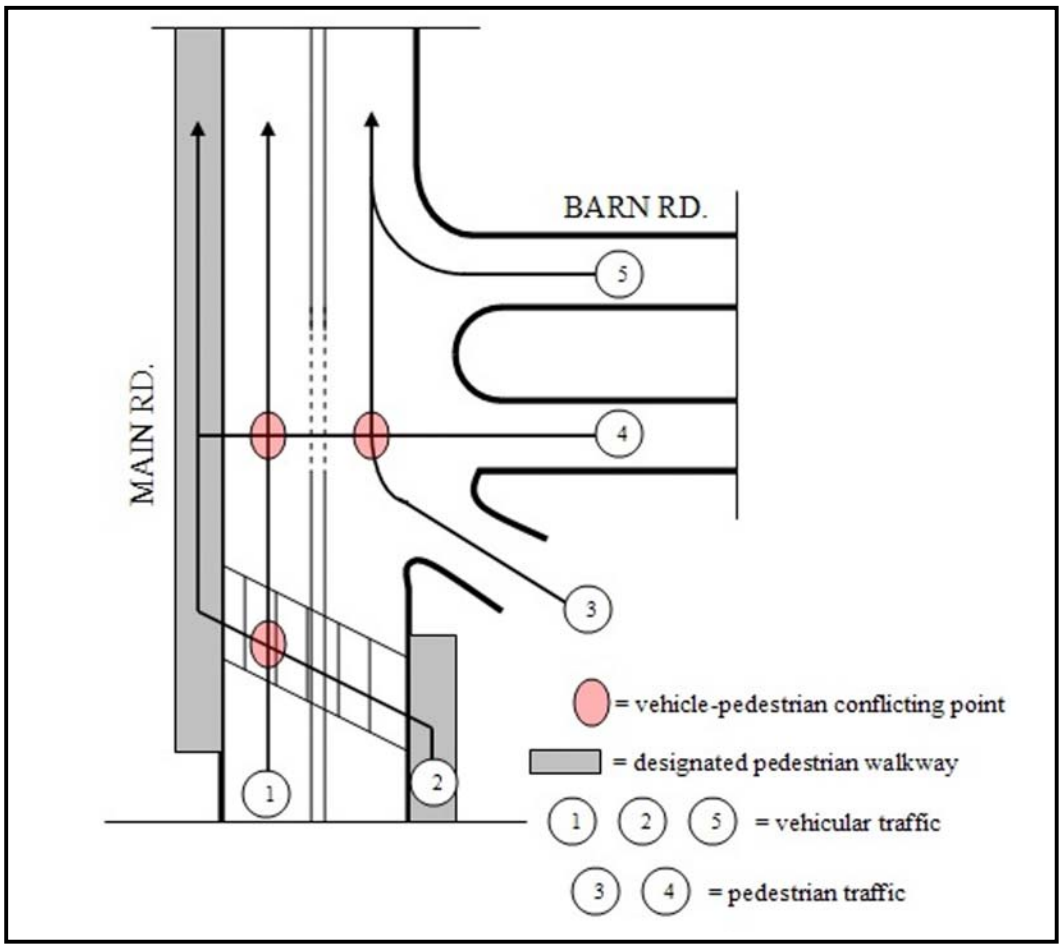


FIGURE 2.9: Vehicle-Pedestrian Conflict Diagram at Barn Rd and Main Rd Intersection

2.7 Identified Problems

Based on the existing conditions and field observations, the problematic areas of vehicle-pedestrian traffic operations are identified as follows:

- Traffic congestion and delays entering the park before the show time
- Traffic congestion and delays exiting the park after the performances
- Vehicle-pedestrian conflicts
- Vehicle and Pedestrian Signing, Lighting, and Walkways

These problems and proposed recommendations will be addressed in the following chapters.

CHAPTER 3 VEHICULAR TRAFFIC OPERATIONS

The chapter provides a detailed analysis of vehicular traffic operations at Wolf Trap National Park for Performing Arts. Traffic circulation and parking operations within the park are investigated by a method of microsimulation. Incoming vehicles are simulated on a computer as they travel on the actual roadway network. Statistics are collected throughout the course of simulations in order that traffic operational performances of the system can be evaluated. The chapter consists of three sections. The first section presents a simulation of the existing parking operations before the show time. The second section provides a deterministic analysis of the exit process of traffic. Simulation is not used for the exit process because we already know that every vehicle in the system desires to get out the system at the same time. In addition, capacity of the roadway can easily be determined. Thus, a deterministic analysis is adequate for analyzing the exit process. The last section gives a recommendation for traffic and parking operations.

3.1 Simulation of the Existing Parking Operations

In this study, data collections were conducted to gather relevant information to develop a simulation model. This includes loading time at each parking lot, average occupancy rate, percentage of arriving vehicles for different time, proportion of visitors based on different permits, and available spaces at each parking lot. A sold-out show with 7000 attendance is simulated. It is assumed that the performance starts at 8 pm and the average occupancy rate is 2.4 persons per vehicle. Five percent of visitors arrives before 5 pm. 15 percent arrives between 5 pm and 6 pm. 80 percent arrives evenly between 6 pm and 8 pm. 90 percent of visitors are normal visitors without special parking permits. Two percent of patrons are handicapped. One percent of visitors is holding gold permits and seven percent are VIP visitors. With this information, a simulation model is developed to emulate the existing parking operations. Table 3.1 summarizes the performance measures of the system based on the above information.

TABLE 3.1: Performance Measures of the Simulated System Based on the Current Operations from 6 to 8 pm

MEASURE	AVERAGE	MAXIMUM
Waiting Time of Normal Visitors from Route 7	8.11 seconds	21.47 seconds
Waiting Time of Normal Visitors from Toll Rd	33.05 seconds	190.54 seconds
Waiting Time of VIP visitors	28.30 seconds	183.67 seconds
Waiting Time of Handicapped visitors	26.99 seconds	158.08 seconds
Waiting Time of Permit visitors	16.07 seconds	18.95 seconds
Waiting Time on Trap Road at the Upper Intersection	26.22 seconds	183.84 seconds
Queue Length on Trap Road at the Upper Intersection	5.32 vehicles	48 vehicles

The average waiting time is defined as average delay incurred to visitors before parking not including the travel time on roadways. From Table 3.1, the average waiting time of normal visitors from Toll Rd is the highest among all visitors as they are the majority of visitors but can not use the upper intersection to access the park. As anticipated, the normal visitors from Route 7 have the lowest average delay since they can self-park in the West Lot. The average waiting time of VIP and handicapped visitors are 28.30 and 26.99 seconds, respectively, which are approximately 5 to 6 seconds lower than that of the normal visitors from Toll Rd due to the fact that they hold permits to access the upper intersection. However, the average waiting time of the permit visitors is significantly lower than those of VIP and handicapped visitors because most of them arrive at the park before the peak period. The simulated results show that the maximum waiting time at the upper intersection is 183.84 seconds or roughly 3 minutes, which are considered acceptable for a typical parking operation. The average queue length on Trap Road is about 5 vehicles but the maximum queue length is 48 vehicles, which is observed 15 minutes before the show time as expected. There are 308 vehicles parking outside along Trap Rd.

These results indicate that the existing parking operations are adequate for the current demand when all parking spaces are available in a good weather condition. On a rainy day, turf parking areas are saturated and can not be used. Number of off-street parking will be increased; therefore, more paved parking areas are required.

3.2 Analysis of the Current Exit Process

According to the field observations, there are only two exit routes from Wolf Trap National Park: 1) the north exit via Route 7 (Leesburg Pike) and 2) the south exit via Toll Rd (VA-267) as shown in Figure 2.5. The gate at the upper intersection of the West Lot is closed at all times with the notion that the exit processes of both the Westside and the Eastside parking lots will finish at the same time. Opening this gate will not expedite the exit process of the entire system because the bottleneck remains at the one-lane roadway approaching the bridge over VA-267. A simple deterministic model is developed to evaluate the current exit process. Assume that 7000 visitors all leave the Filene Center at 10 pm with the average occupancy rate of 2.4 persons per vehicle. According to the 2001 traffic count report from Virginia Department of Transportation (VDOT), the annual average daily traffic (AADT) of the Toll Rd portion between Hunter Mill Rd and Leesburg Pike is 124000 (both direction). Therefore, an estimate of the flow rate on Toll Rd between 10 pm to 12 am is assumed to be 1033 (~ 0.05*124000/6) vehicles per hour per lane.

Merging capacity, the ability of the mainstream road to absorb merging vehicles per hour, of Toll Rd can be determined using the methodology provided in the Highway Capacity Manual 2000. Let us assume that a 3-second critical gap (the minimum time that allows merging entry for one minor-stream vehicles) and a 1.5-second follow-up time (the time between departure of one vehicle from the minor street and the departure of the next under a continuous queue condition) are applicable to the existing traffic condition.

$$\text{Merging Capacity of VA - 267} = \frac{q \cdot e^{-\frac{q}{3600} t_C}}{1 - e^{-\frac{q}{3600} \cdot t_F}}$$

where q = VA - 267 flow rate (vehicles per hour per lane)

t_C = the critical gap (3 seconds)

t_F = the follow - up time (1.5 seconds)

$$\therefore \text{Merging Capacity of VA - 267 Road} = 1033 \times \frac{e^{-\frac{1033}{3600} \times 3.0}}{1 - e^{-\frac{1033}{3600} \times 1.5}} = 1250 \text{ vehicles per hour}$$

Similarly, capacity of the signalized intersection of Leesburg Pike and Towlson Rd (the north exit route) is determined. The field observation shows that this intersection operates under a pretimed control system with the cycle length of 115 seconds and the green time given to the Towlson Rd approach is 64 seconds. With a computation in accordance with the Highway Capacity Manual 2000, capacity of this intersection can be approximated as shown in Figure 3.1 (assume an ideal saturation flow rate of 1900 vehicles per lane per hour of green).

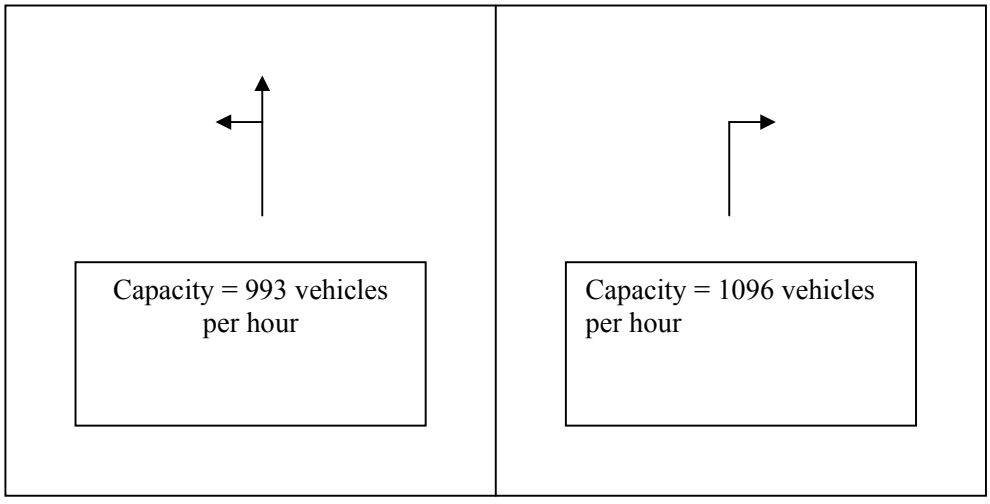


FIGURE 3.1: Capacity of the Northbound Approach Intersection of Leesburg Pike and Towlston Rd.

The capacity of the through and left-turn movement of the approach is 993 vehicles per hour and that of the right-turn movement is 1096 vehicles per hour. Based on this information, the total capacity of the existing roadway network at Wolf Trap National Park is roughly 3339 (~ 1250+1096+993) vehicles per hour. Note that the capacity of the through and left-turn movement of the intersection of Towlston Rd and Leesburg Pike cannot be fully utilized because 70 percent of the traffic makes a right-turn at this intersection.

According to the field observations, the number of vehicles that exit the system at the two routes is estimated as shown in Figure 3.2.

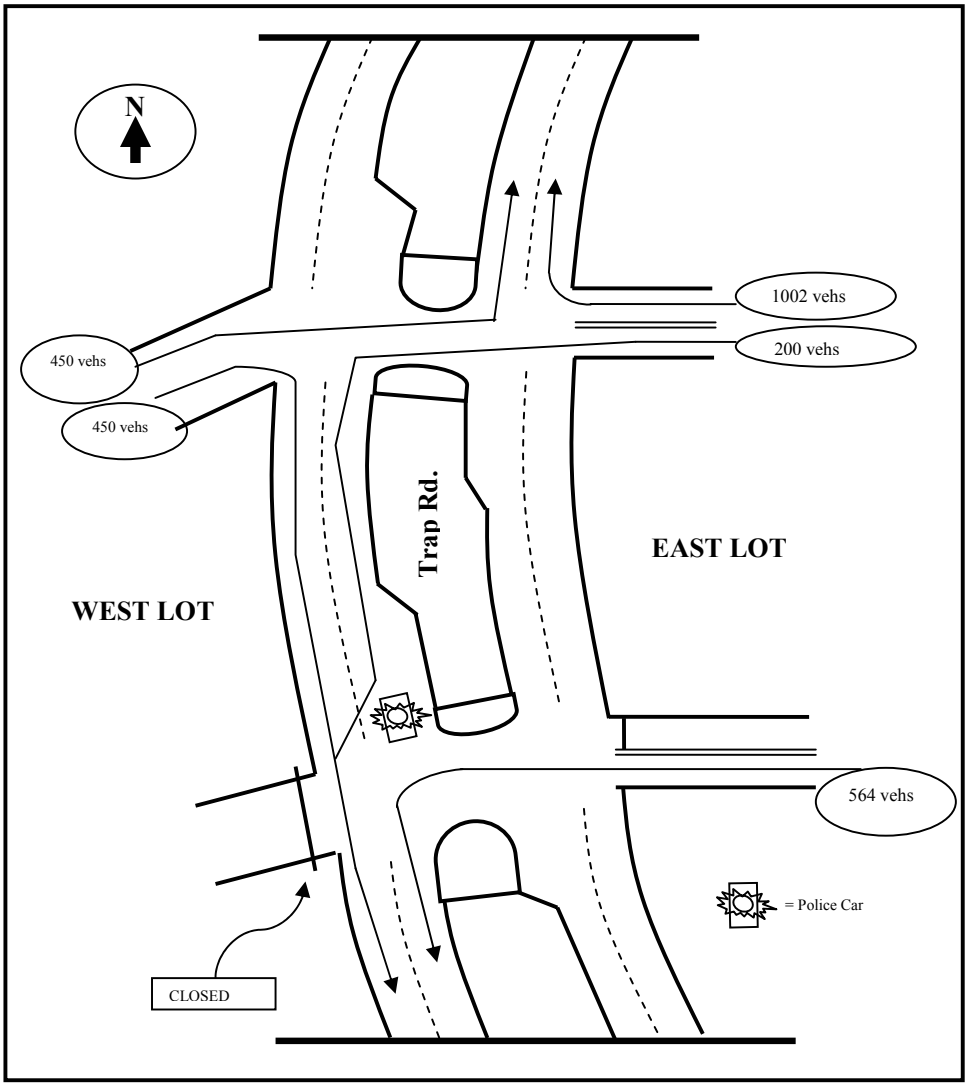


FIGURE 3.2: Number of Vehicles Currently Exiting From the Park

Therefore, time to clear the traffic from the two main exit routes can be estimated as follows.

$$\text{Number of vehicles exit at VA - 267 (Toll Rd.)} = 450 + 564 + 200 = 1214 \text{ vehicles}$$
$$\text{Number of vehicles exit at VA - 7 (Leesburg Pike)} = 1002 + 450 = 1452 \text{ vehicles}$$
$$\text{Number of vehicles turn right at VA - 7} = 0.7 * 1452 = 1016 \text{ vehicles}$$
$$\text{Number of vehicles turn left at VA - 7} = 1452 - 1016 = 436 \text{ vehicles}$$
$$\text{Time to clear all vehicles at VA - 267} = \frac{\text{Number of vehicles}}{\text{Merging Capacity}} = \frac{1214}{1250} \cdot 60 = 58.27 \text{ minutes}$$
$$\text{Time to clear all vehicles turn right at VA - 7} = \frac{\text{Number of vehicles}}{\text{Capacity}} = \frac{1016}{1096} \cdot 60 = 55.62 \text{ minutes}$$
$$\text{Time to clear all vehicles turn left or go straight at VA - 7} = \frac{\text{Number of vehicles}}{\text{Capacity}} = \frac{436}{993} \cdot 60 = 26.34 \text{ minutes}$$

From the above calculation, it is indicated that the time to clear all vehicles from the park after the performance is 58.27 minutes and the last vehicle gets out from the system at Toll Rd. This is consistent and comparable to the field observations. However, there are still some rooms for improvements for the exit process. This will be discussed in the following section.

3.3 Recommendations to Parking and Traffic Operations

This section provides recommendations to parking and traffic operations in the park. It consists of two parts. The first part presents recommendations to parking operations before the show time. The second part provides recommendations to traffic operations for the exit process after the performance.

3.3.1 Recommendations to Parking Operations

The existing parking operations are considered adequate with the current number of parking crews. The maximum delay to visitors is less than 200 seconds (~ 3.5 minutes) and the maximum queue length on the Trap Rd. is 48 vehicles. This occurs when all on-site parking spaces are filled up or approximately 15 minutes before the show time. Apparently, in order to improve the parking operations, the following recommendations should be considered.

1. Increasing number of parking crews will allow parking operations to take place simultaneously at different parking lots. This will reduce the AVERAGE waiting time of visitors.

2. Better signing on the Trap Rd should be installed. This will reduce number of visitors without special permits stopping at the upper intersection. The AVERAGE queue length will significantly decrease.

3.3.2 Recommendations to Traffic Operations After the Show

The results from the previous section show that the bottleneck of the existing system is the exit process at Toll Rd. The first obvious but trivial recommendation is to increase the capacity of this bottleneck. However, it is extremely difficult to be implemented due to the fact that this requires a major expansion of not only the interchange but also Trap Rd, which will inevitably incur a large amount of construction costs and disrupt traffic flow on Toll Rd and the neighboring residential areas. This recommendation will no longer be discussed. According to the analysis in section 3.2, capacity of the northbound approach of the intersection of Leesburg Pike and Towlston Rd has not been fully utilized yet. Therefore, the second recommendation is to increase capacity of this intersection and redirect some vehicles that currently use the south exit or Toll Rd to the north exit. This recommendation can readily be implemented. It requires a new lane designation and a slight modification to the existing signal setting at the intersection of Leesburg Pike and Towlston Rd. The details of this recommendation are provided in the following paragraphs.

Step 1: Reorganize the exit pattern of vehicles.

Currently, vehicles in Lots 1, 2, and 4 are directed to the upper intersection and are exiting the park via Toll Rd. Vehicles, parked in the Dust Bowl, the Gil's Hill, and Lot 3, are directed to the lower intersection and must exit via Route 7 (Leesburg Pike). At the West Lot, visitors have two alternatives. They can depart via either Toll Rd or Route 7 depending on which lane they occupy. The East Lot vehicles are allowed to exit at either the lower or the upper intersections but they are all directed to Toll Rd.

The recommended exit pattern is to redirect all vehicles in the Dust Bowl and Lot 3 to the upper intersection. These vehicles must exit the park via Toll Rd. However, ALL vehicles that park in the West Lot are directed to the north exit route via Route 7

(Leesburg Pike). They are no longer allowed to make a right turn to exit via Toll Rd. The gate on Barn Rd of the Gil's Hill is closed to traffic. Anything else remains as the current operations. With this new exit pattern, number of vehicles exiting the system during a typical sold-out show can be summarized as shown in Figure 3.3.

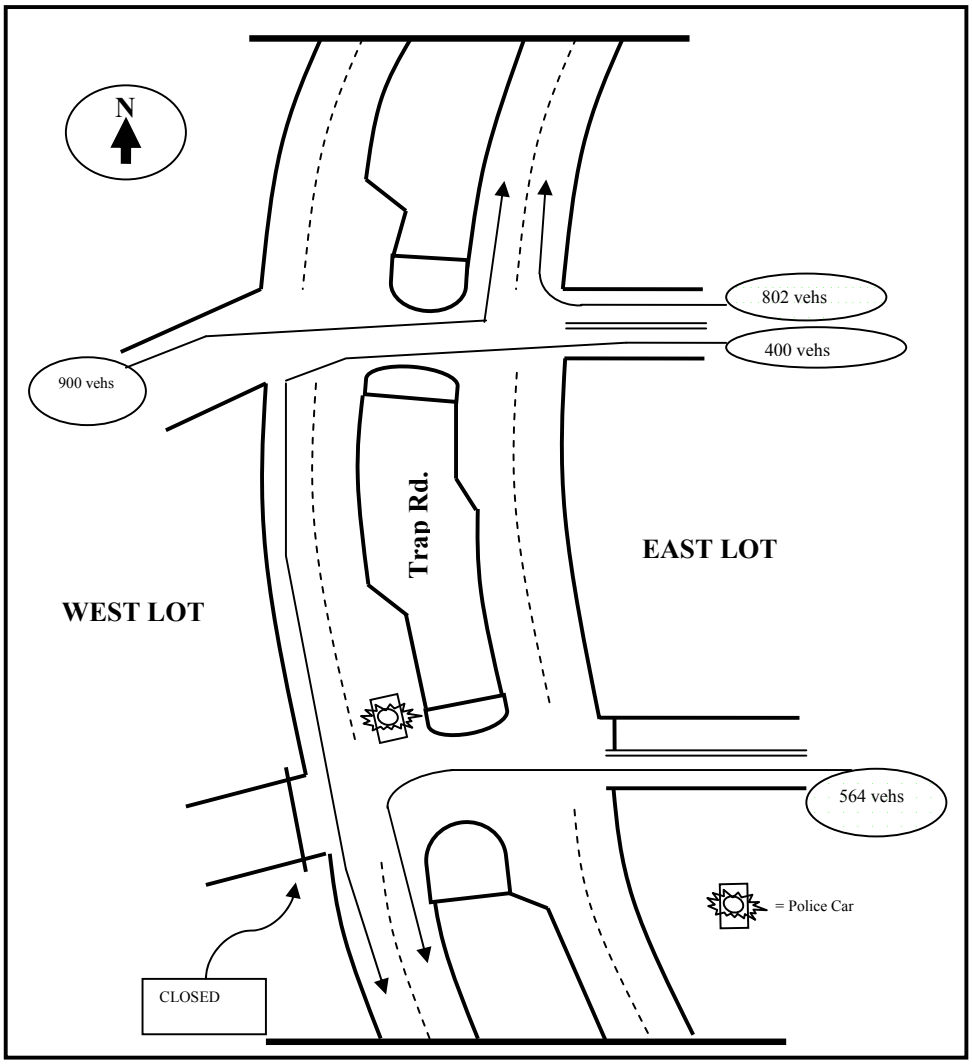


FIGURE 3.3: New Exit Pattern of Traffic

Step 2: Increase capacity of the northbound approach at the intersection of Leesburg Pike and Towlston Rd.

Currently, there are two lanes at the northbound approach of this intersection. The first lane or the median lane allows only through and left-turn movements and the second lane allows right-turn movement. However, the majority of traffic using this intersection are right-turn vehicles. This results in an underutilization of the median lane. Hence, the proposed recommendation is to redesign the lane designation of the northbound approach at the intersection. Figure 3.4 illustrates the existing and the proposed lane designations of this intersection.

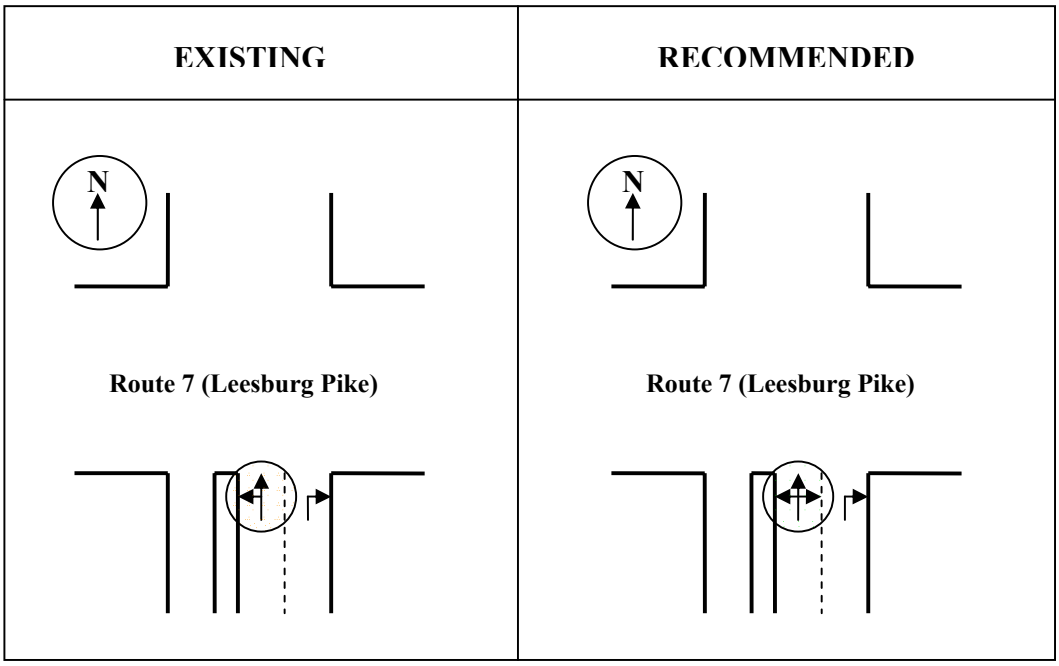


FIGURE 3.4: Lane Designation at the Northbound Approach of the Intersection of VA-7 (Leesburg Pike) and Towlston Rd

Also, turning on red is not allowed from the median lane of the northbound approach. A no-turn-on-red sign should be installed at the intersection as shown in Figure 3.5.

Figure 3.5: NO-TURN-ON-RED Sign

The new signal setting at the intersection of Leesburg Pike and Towlston Rd is slightly modified to accommodate the southbound traffic at this intersection as shown in Figure 3.6. Note that the new signal timing plan will reduce capacity of the eastbound and westbound approach by less than 100 vph. This will not adversely affect the traffic operations of these two approaches because traffic volumes from 10 pm to 11 pm are relatively light.

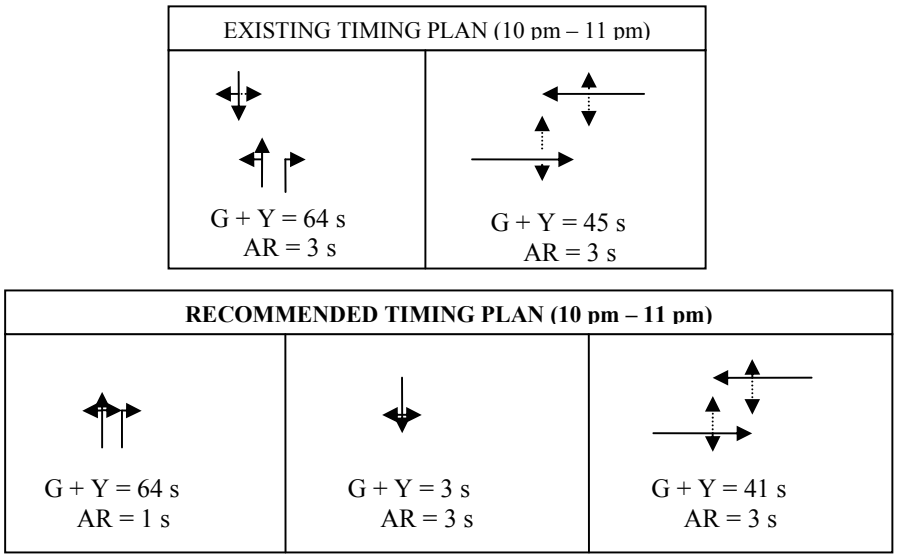


Figure 3.6: Recommended Signal Timing Plan at the Intersection of Leesburg Pike and Towlston Rd (from 10 pm to 11 pm)

A deterministic traffic analysis is conducted to verify the effect of these recommendations on traffic operations.

$$\text{Number of vehicles exit at VA - 267 (Toll Rd.)} = 764 + 200 = 964 \text{ vehicles}$$

$$\text{Number of vehicles exit at VA - 7 (Leesburg Pike)} = 802 + 900 = 1702 \text{ vehicles}$$

$$\text{Time to clear all vehicles at VA - 267} = \frac{\text{Number of vehicles}}{\text{Merging Capacity}} = \frac{964}{1250} \cdot 60 = 46.27 \text{ minutes}$$

$$\text{Time to clear all vehicles at VA - 7} = \frac{\text{Number of vehicles}}{\text{Capacity}} = \frac{1702}{1096 + 993} \cdot 60 = 48.88 \text{ minutes}$$

From the above calculation, it is indicated that the time to clear all vehicles from the park after the performance is 48.88 minutes and the last vehicle gets out from the system at Toll Rd. A ten (from 58.27 to 48.88)-minute reduction of the visitor delay can be anticipated from these recommendations.

Note that these recommendations should be considered when the number of visitors is more than 5,000. If the number of visitors is less than 5,000, the difference in time to clear all traffic using the existing plan and the proposed plan will be insignificant.

CHAPTER 4 SIGNING, LIGHTING, AND WALKWAYS

This chapter presents a discussion on signing, lighting, and walkway conditions within the park. The important elements are identified and summarized in the following paragraphs.

A. Barricades along the Walkway at the Intersection of Main Rd and Barn Rd

Barricades are currently installed along the walkway at the intersection of Main Rd and Barn Rd as shown in Figure 4.1.

Figure 4.1: Barricades along the Walkway at the Intersection of Main Rd and Barn Rd

The purpose of installing these barricades is to discourage pedestrians from crossing Main Rd at this location and to direct pedestrians to the nearby designated crosswalk. There are still a large number of visitors crossing Main Rd at this location even though the park ranger who controls this intersection suggests visitors to cross at the nearby designated crosswalk. The current practice of installing barricades should be continued.

The barricades should also be extended to the pedestrian tunnel as some visitors cross Main Rd before reaching this intersection. However, permanent barricades such as concrete barriers are not recommended because heavy vehicles require a large turning radius at this intersection, which could damage the barricades.

B. Vegetation at the Access Ramp to VA-267 (Toll Rd)

The exit process occurs at the two exit routes. The south exit route is via Toll Rd. All vehicles that use this route have to make a left turn onto the access ramp as shown in Figure 4.2.

Figure 4.2: The Access Ramp to VA-267 (Toll Rd)

At night drivers can hardly see the sign because of the vegetations. This can slow down the exit process. Therefore, it is recommended that the vegetations should be cleared.

C. One-Way Signs at the Upper Intersection

Figure 4.3 shows the One-Way signs located at the upper intersection. These signs were installed by Virginia Department of Transportation (VDOT) in 2002. According to the historical traffic data, there has been no accident related to wrong-way turning reported long before the installation of these signs.

Figure 4.3: One-way signs

However, these signs should be kept as they are due to the recommendations in Manual on Uniform Traffic Control Devices (MUTCD) 2000 that one-way signs should be installed at intersections with divided highways that have median widths greater than 30 ft (9 m). Note that the median of the upper intersection is greater than 30 ft.

D. Painted Crosswalk at the Intersection of Main Rd and Barn Rd

As mentioned earlier in chapter 2, pedestrian-vehicle conflicts are observed at the intersection of Main Rd and Barn Rd, especially during the exit process of traffic. Some

pedestrians walk along Barn Rd to cross Main Rd at this intersection. Therefore, in order to reduce number of these pedestrians. It is recommended that two exit gates from the Filene Center, 1) the one near the ranger station, and 2) the one behind the administrative building, be closed at the end of the performance. This will result in approximately five more minutes to clear visitors at the Filene Center, which will not impact or incur higher delays to the vehicular traffic operations. In addition, the number of pedestrians who cross Main Rd from Barn Rd should be significantly reduced. Nevertheless, it is still recommended that pathway lighting be installed along Barn Rd so that pedestrians are visible to vehicles at this intersection.

E. Sign for Permits and Handicaps Entrance

With the existing traffic operations, permit holders and handicaps are allowed to enter the park using the upper intersection. Visitors without permits must enter the park via the lower intersection. There are two signs that inform visitors this restriction. Both of them are posed at the upper intersection. Most visitors are likely to make a right turn at this intersection even though they do not have any parking permits. This is because the signs are too close to the intersection. It does not allow enough time for visitors to digest the information. It also incurs delays to visitors and creates a traffic backup on Trap Rd. It is recommended that a new sign be installed 130 ft upstream of the upper intersection. The new sign should be read "General Parking Use Second Right" or "Only Handicaps and Permits Use Next Right" as shown in Figure 4.4.

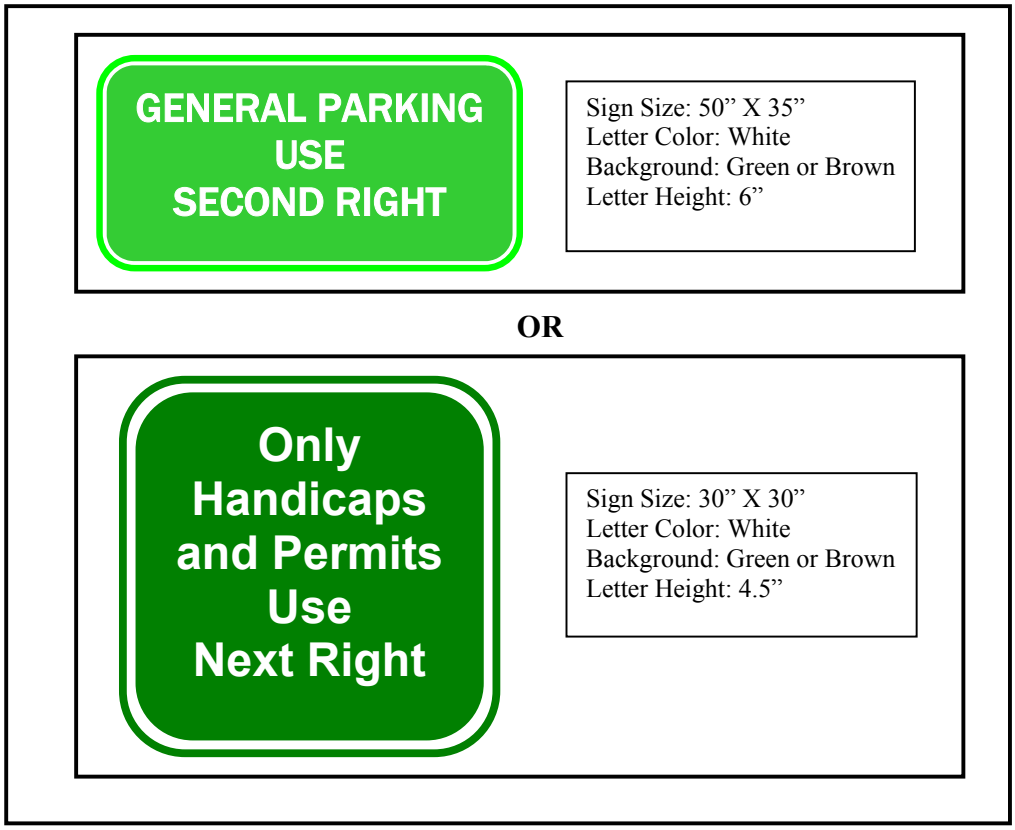


Figure 4.4: The New Recommended Sign at the Upper Intersection

F. Lighting for Pedestrians along Trap Rd

Generally, a sold-out show draws approximately 7000 visitors. Some of the visitors park along the shoulder of Trap Rd because of inadequate parking spaces in the park. These visitors cross Trap Rd and use the emergency entrance to get an access to the Filene Center. Figure 4.5 shows pedestrians crossing Trap Rd at this location.

Figure 4.5: Pedestrians Crossing Trap Rd

It is recommended that lights should be installed along Trap Rd. This will make pedestrians more discernable to vehicles. In addition, a pedestrian walkway at the emergency entrance should also be provided.

G. Divided Highway Ends Signs at the Upper Intersection

Currently, there are two Divided-Highway-Ends signs at the upper intersection as shown in Figure 4.6.

Figure 4.6: Divided-Highway-Ends Sign

According to the MUTCD 2000, these signs should be installed at the end of a section of physically-divided highway (not an intersection or junction) as a warning of two-way traffic ahead. It is, therefore, recommended that these two signs be relocated to the end of the median of Trap Rd toward the bridge crossing Toll Rd.

H. Walkways for Pedestrians Parking Outside

For a typical sold-out show performance, approximately 300 vehicles can not be accommodated by the on-site parking lots. The majority of these vehicles park on the shoulder of Trap Rd extending from the bridge over Toll Rd to the neighboring residential area. Pedestrian traffic is generated accordingly from Trap Rd to the Filene Center. It is recommended that walkways for these pedestrians should be provided to minimize vehicle-pedestrian conflicts. The existing designated walkway should be expanded to the emergency entrance on Main Rd. Figure 4.7 exhibits a layout of the proposed walkways for pedestrians.

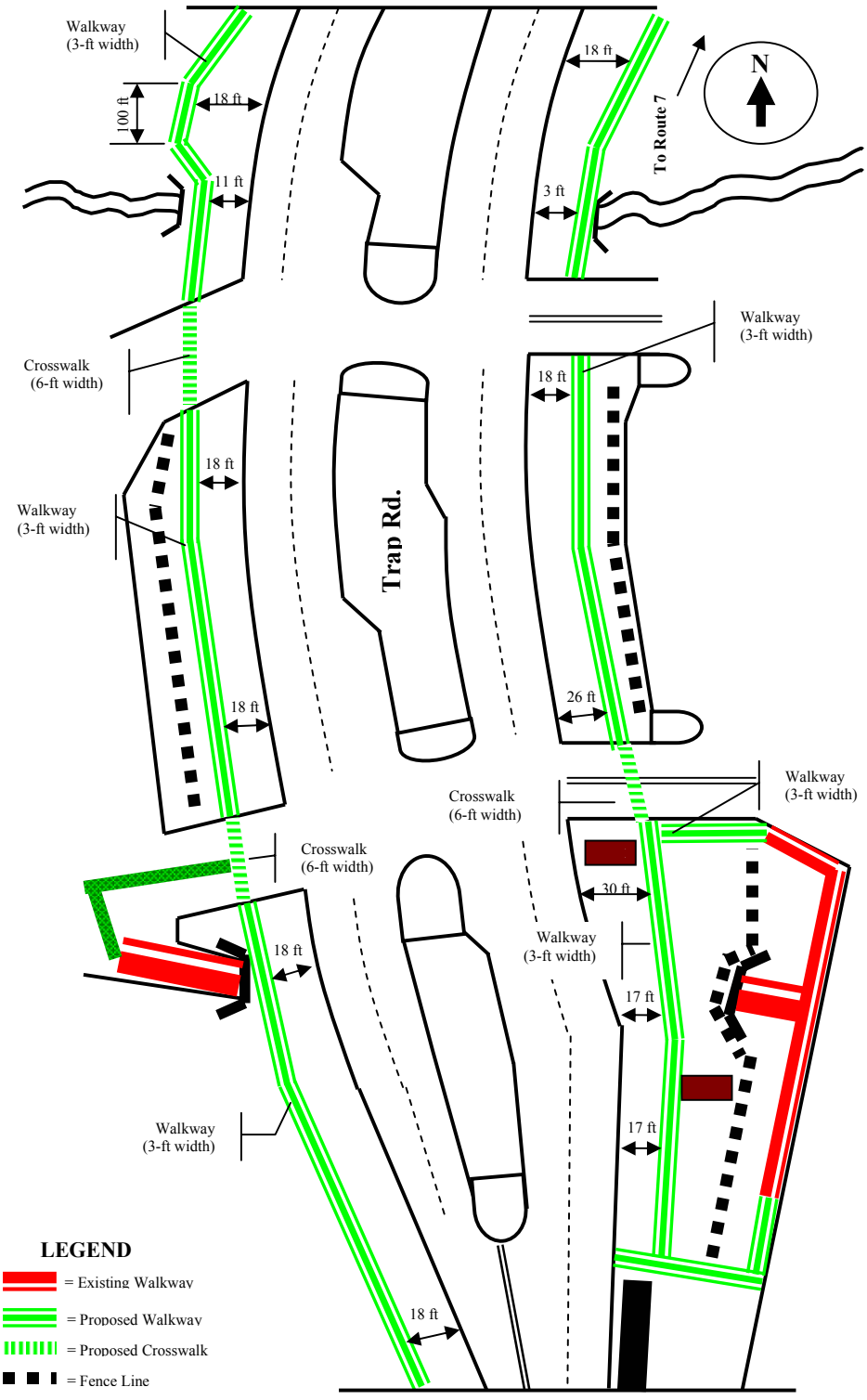


FIGURE 4.7(A): Layout of the Proposed Walkways

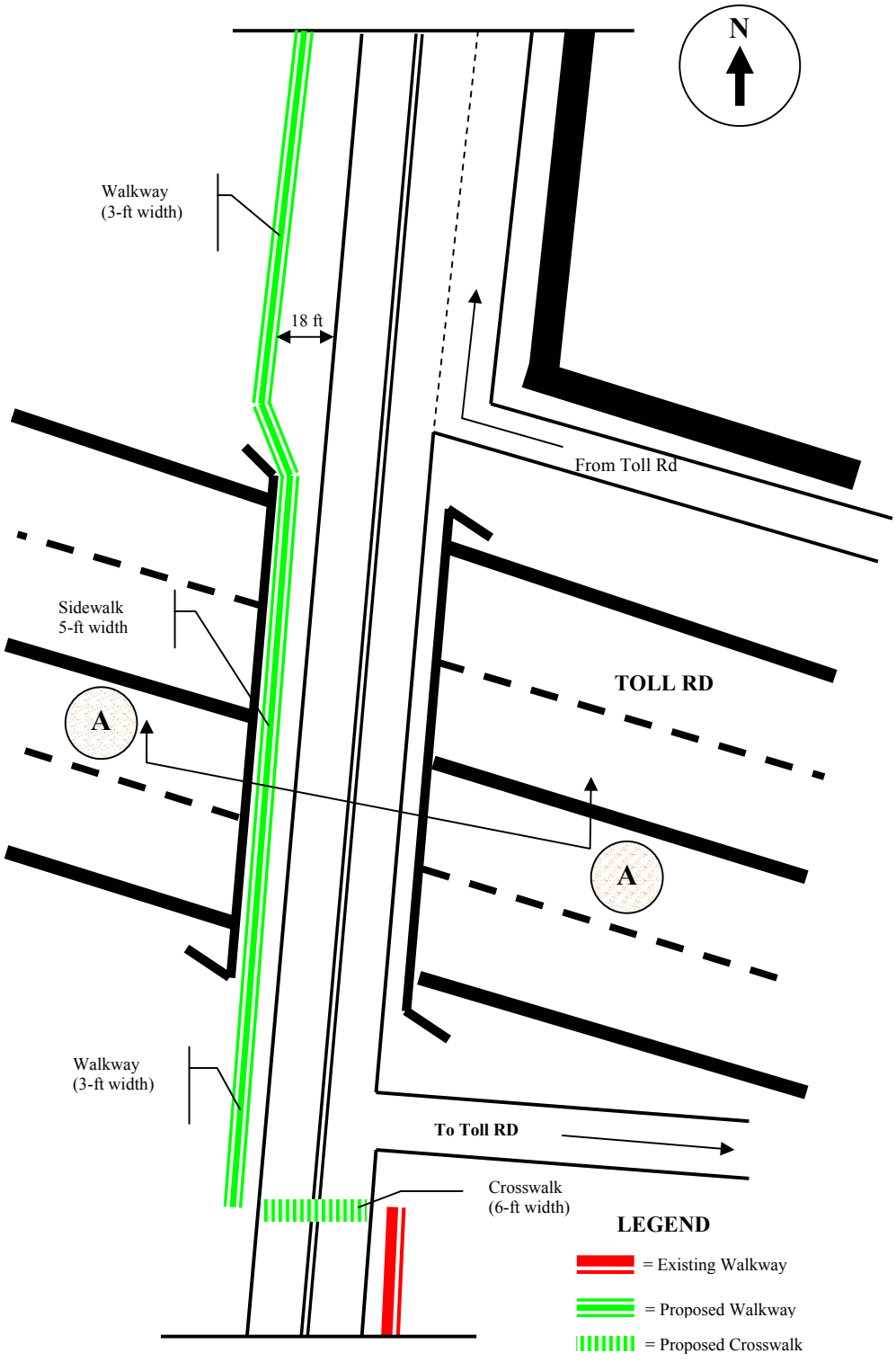
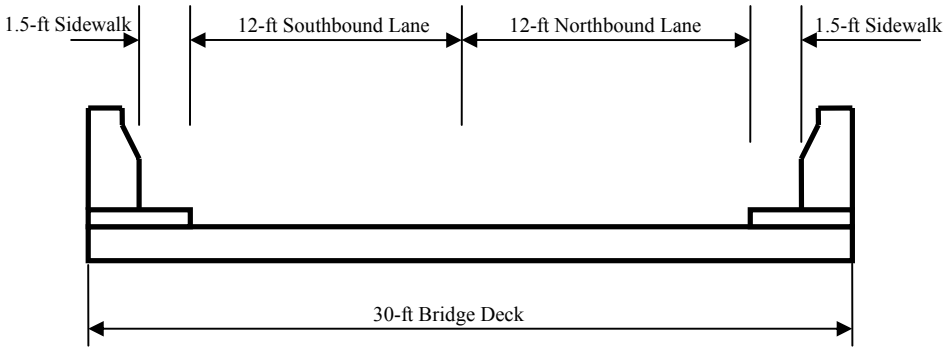
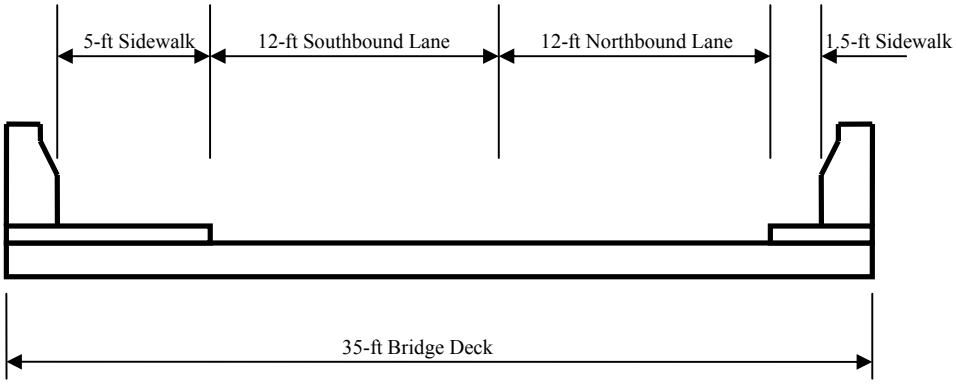


FIGURE 4.7(B): Layout of the Proposed Walkways



(a) Existing Bridge



(b) Recommended Bridge

SECTION A-A

FIGURE 4.7(C): Layout of the Proposed Walkways

Note that the walkways shown in Figures 4.7(A) and 4.7(B) should be separated from the vehicles parked along the shoulder of Trap Rd by wooden barriers as provided along the Circle.

CHAPTER 5 CONCLUSIONS

As visitation to the national parks grows tremendously every year, the challenge of ensuring resource protection while accommodating visitors and providing enjoyable experiences for them requires planning and sustainable, environmentally-friendly roads and transportation systems. Ford Motor Company in partnership with the National Park Foundation provides a grant for Ponlathep Lertworawanich, the author of this report, to conduct a traffic impact study at Wolf Trap National Park for The Performing Arts.

This study describes the existing conditions and provides recommendations for parking operations and traffic circulations in the park.

The existing parking operations and traffic circulations in the park are summarized as follows:

1. The traffic circulation within the park for the incoming traffic before the show is operating in an orderly manner.
2. The parking operations are operating in an exceptionally good level given limited resources. The AVERAGE delay incurred to visitors before parking is less than 35 seconds with the MAXIMUM of less than 3.4 minutes. These are considered reasonably acceptable for a major concert event.
3. The exit process after the show occurs in a relatively disorder manner due to the fact that most visitors desire to leave the park at the same time. It usually takes 55 – 60 minutes for a sold-out show (~7000 visitors) to clear all visitors out of the park.
4. Ineffective signing is observed at some locations in the park.
5. Insufficient on-site parking spaces for a sold-out show (2931 parking spaces available but requires approximately additional 300 spaces).

Upon the completion of this traffic impact study, the following recommendations are identified:

6. A new exit pattern is proposed to reduce delays to visitors after the show. The details of this new pattern are provided in chapter 3. Note that this new

pattern was first implemented on August 5, 2003 and has still been tested to verify its advantages.

7. For a sold-out show, it is recommended that unnecessary park personnel's vehicles be parked in the parking lot at the Barns of Wolf Trap if possible. This will reduce the number of visitors parking along the shoulders of Trap Rd and relieve parking problems.
8. New lighting and signing to enhance safety and smoother flow of pedestrian and vehicular traffic should be considered at specific locations in the park as discussed in chapter 4 of this report.
9. A further economic analysis should be conducted to identify advantages and disadvantages of promoting the use of public transportation. If public transportation, a more environmental friendly approach, is to be used in the future, a new marketing effort is requisite. This will demand a greater corporation among related agencies such as the National Park Service and the Wolf Trap Foundation.

REFERENCES:

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